# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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## AN ANALYSIS OF THE AIRSPEEDS AND NORMAL ACCELERATIONS OF BOEING B-247 AND B-247D AIRPLANES IN COMMERCIAL TRANSPORT OPERATION

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## SUMMARY

Acceleration and airspeed data taken on Boeing B-247 transport airplanes operated over transcontinental routes of the United States during the period from 1933 to 1937 have been analyzed. The results show that, on the average, the placard speed would be exceeded once in about $9.5 \times 10^5$ flight miles and the limit gust load factor would be exceeded once in about $2.5 \times 10^6$ flight miles. The results of operations of the B-247 airplanes in comparison with the results of operations of other airplanes show larger than average flight loads, a high operating-speed ratio, but route roughness appears to be about average. These results together with analyses made in the past indicate that operating speed in regions of turbulent air is a significant factor in the operational life of the airplane.

## INTRODUCTION

The results of analyses of V-G data given in references 1 to 5 have shown that the flight loads of airplanes operated in commercial transport service are influenced by operating speeds and by forcasting and dispatching practices as reflected in differences between operations during the prewar and wartime periods. In line with previous investigations of airplane flight loads and operating speeds, this paper presents the results of an analysis of V-G records obtained on Boeing B-247 transport airplanes. The available data are summarized and the flight results are compared with the results of analyses made in references 1 to 5.

## SYMBOLS

| | |
|---|---|
| $K$ | gust-alleviation factor |
| $V_L$ | design maximum level-flight speed, miles per hour |
| $V_{max}$ | maximum indicated airspeed on V-G record, miles per hour |
| $V_o$ | indicated airspeed at which maximum positive or negative normal acceleration increment occurs on V-G record, miles per hour |
| $V_p$ | probable airspeed at which maximum normal acceleration increment will most likely occur, miles per hour |
| $P_V$ | probability that maximum indicated airspeed on V-G record will exceed a given value |
| $P_{\Delta n}$ | probability that maximum normal acceleration increment on V-G record will exceed a given value |
| $\tau$ | average flight time per record, hours |
| $\Delta n_{max}$ | maximum positive or negative normal acceleration increment on V-G record, g units |
| $\overline{V}_{max}$, $\overline{V}_o$, $\overline{\Delta n}_{max}$ | average values of distributions of $V_{max}$, $V_o$, and $\Delta n_{max}$, respectively |
| $\sigma_V$, $\sigma_o$, $\sigma_{\Delta n}$ | standard deviations of distributions of $V_{max}$, $V_o$, and $\Delta n_{max}$, respectively |
| $\alpha_V$, $\alpha_o$, $\alpha_{\Delta n}$ | coefficients of skewness of distributions of $V_{max}$, $V_o$, and $\Delta n_{max}$, respectively |

## SCOPE AND EVALUATION OF DATA

Forty-two V-G records representing 12,494 hours of flight were on hand for the present analysis. The records were obtained from five airplanes operated by one airline during the period from July 1933 to April 1937 on routes across the United States. Two of the airplanes were operated as B-247 type and, after conversion, were operated as B-247D type. The records were supplied to the Langley Aeronautical Laboratory of the NACA by the operating airline together with dates of installation and removal, number of flight hours per record, and occasional supplementary remarks regarding unusual atmospheric conditions or operating practices.

The values of airplane design characteristics obtained from the Civil Aeronautics Administration and from the operating airline differ slightly in some respects for the B-247 and the B-247D airplanes. The differences are small, and the final results were not appreciably affected by the use of one set of characteristics for both airplane types. Consequently, the values used for all computation made herein are as follows:

| | |
|---|---|
| Gross weight, pounds | 13,400 |
| Gross wing area, square feet | 836 |
| Wing span, feet | 74 |
| Mean aerodynamic chord, feet | 11.68 |
| Slope of lift curve, per radian | 4.22 |
| Design maximum level-flight speed, $V_L$, miles per hour | 180 |
| Placard speed, miles per hour | 225 |
| Limit gust load factor, g units | 3.48 |
| Gust-alleviation factor, K | 1.00 |

The limit gust load factor of 3.48g was determined by use of the gust-load-factor formula on the basis of the requirements set forth in reference 6. The placard never-exceed speed is computed in accordance with reference 7 to be $1.25V_L$ or 225 miles per hour.

Thirty V-G records representing 9,168 flight hours within a range of 150 to 475 flight hours, figure 1, were used for the statistical analysis. The range of records used is considered to be satisfactory for the analysis. The method of analysis (reference 8) suggests use of a minimum of 15 records, representing not less than 2500 flight hours within a range of about 30 percent of the total variation of flight hours, to obtain satisfactory results. However, only fourteen records fall within this limit and these records would fall within the zone shown in figure 1. A check analysis applied to those fourteen records indicated that departure from the ranges and selection of records suggested in the method was not important in this case since the results did not differ appreciably from those given herein. Two of the records available for analysis, for a total of 174 flight hours, were obtained from test flights and were therefore not used. Eighteen of the records used were taken in B-247 airplanes and twelve were taken in B-247D airplanes.

The V-G records used in the analysis were evaluated without attempting to classify acceleration peaks as due to gusts, gust maneuvers, or maneuvers. The assumption is made that all large accelerations at speeds above 100 miles per hour are due to gusts, for experience indicates that most of the large loads imposed during normal transport operations are caused by gusts.

## PRECISION

The precision of the NACA V-G recorder and the limitations of the method of analysis employed are discussed in reference 1. The inherent instrument errors are assumed not to exceed $\pm 0.2g$ for acceleration and 3 percent of the maximum airspeed range of the instrument.

## ANALYSIS AND RESULTS

The V-G data have been analyzed in accordance with the method of reference 8. From each record six quantities were read: the record flight time, the maximum indicated airspeed $V_{max}$, the maximum positive and maximum negative acceleration increment $\Delta n_{max}$, and the indicated airspeeds at which these accelerations were experienced $V_o$. The frequency distributions of $V_{max}$, $\Delta n_{max}$, and $V_o$ are given in table I. Because of the essential symmetry of positive and negative acceleration increments, the values of $\Delta n_{max}$ were sorted and tabulated without regard to sign. The mean values $\overline{V}_{max}$, $\overline{\Delta n}_{max}$, and $\overline{V}_o$, the standard deviation $\sigma$, and the coefficient of skewness $\alpha$, have been calculated (reference 9) for each distribution and are also given.

The statistical parameters were used to calculate Pearson Type III probability curves which, as indicated in reference 8, have been assumed to give reasonable representations of V-G data. The Pearson probability curves were then transformed to curves of average flight miles required to exceed given values of airspeed and normal acceleration increment by multiplying $1/P_V$ and $1/P_{\Delta n}$ by the factor $0.8V_L\tau$, where $\tau = 305$ hours. The transformed probability curves together with the cumulative data are presented in figures 2 and 3. Figure 4 shows the average distances required to exceed limit gust load factor and to exceed the acceleration due to encountering an effective gust velocity of 37.5K feet per second at the probable speed of maximum acceleration occurrence $V_p$. This particular value of gust velocity was selected so that the distance required to exceed the resulting accelerations would be roughly comparable to the distance required to exceed the limit gust load factor. For comparison with results for the B-247 airplane, corresponding results for prewar operations of the five airplane types analyzed in references 1 to 5 are given in figure 4 together with the ratios of probable speed of maximum acceleration occurrance to the design maximum level-flight speed $V_p/V_L$.

In order to compare results from different sets of data, some measure is needed to determine whether the indicated differences in the probabilities of exceeding the larger values of airspeed, acceleration, or gust velocity are significant. Use was made of a criterion of engineering concern (references 1 to 5) that is based on experience and states that differences between probabilities are considered to be significant only if the probabilities differ by more than a ratio of 5:1. Since the scale of flight miles of figure 4 is logarithmic, the 5:1 criterion for significant differences may be represented for purposes of comparison by a constant length in the figure.

## DISCUSSION

Inspection of figures 2 and 3 indicates that the agreement between the computed curves and the data is reasonably good. The differences shown are within the precision of the instrument. Figure 2 shows the placard speed will be exceeded, on the average, once in about $9.5 \times 10^5$ flight miles. Figure 3 indicates the limit gust load factor will be exceeded, on the average, once in about $2.5 \times 10^6$ flight miles.

Examination of figure 4 shows that the B-247 airplanes attain the limit gust load factor in a smaller number of flight miles than most of the other airplanes studied. The smaller number of flight miles required for the B-247 airplane to obtain the limit gust load factor can be attributed to the ratio of probable speed of maximum acceleration occurrence to the design maximum level flight speed $V_p/V_L$ being higher for the B-247 than for any other airplane compared. The flight miles to exceed the limit gust load factor differ from those for other airplane operations by as much as 360 to 1; however, negligible differences appear between the operations of the B-247 airplanes and the operations of the DC-3 of airline B, and the operations of the M-130. Comparison of the results for operations of the B-247 airplanes with those for the DC-3 airplanes of airline A, which were operated over substantially the same routes, shows a difference of about 10 to 1 in flight miles. In general, the result for the B-247 airplanes shows that the flight loads, as measured in terms of flight miles to exceed the limit gust load factor, were larger than the average for the whole group.

The route roughness for the B-247 operations, as determined from flight miles required to exceed the acceleration increment due to encountering a fixed effective gust velocity at the probable speed of maximum acceleration occurrence $V_p$, is shown in figure 4 to be not significantly different from the operations of the other airplanes except the M-130 operations. The flight miles required for the B-247 do not differ by more than 8 to-1 from the flight miles required for the M-130.

Consideration of figure 4 shows a trend for the flight miles to exceed the limit gust load factor to increase as the ratio of $V_p/V_L$ decreases. Since, as was previously stated, route roughness of the operations was essentially the same for most of these airplanes, the ratio $V_p/V_L$ in regions of turbulent air is obviously a significant factor in the operational life of the airplane.

## CONCLUDING REMARKS

Analysis of acceleration and airspeed data taken on B-247 airplanes indicates that, on the average, the placard speed will be exceeded once in about $9.5 \times 10^5$ flight miles and the limit gust load factor will be exceeded once in about $2.5 \times 10^6$ flight miles. The operations of B-247 airplanes in comparison with the operations of other airplanes show larger than average flight loads and high operating speed ratio $V_p/V_L$ but route roughness appears to be average. These results together with analyses made in the past indicate that operating speed in regions of turbulent air is a significant factor in the operational life of the airplane.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., November 2, 1948

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TABLE I

FREQUENCY DISTRIBUTIONS AND STATISTICAL

PARAMETERS OF $V_{max}$, $\Delta n_{max}$, and $V_o$

| $V_{max}$ | | $\Delta n_{max}$ | | $V_o$ | |
|---|---|---|---|---|---|
| Velocity (mph) | Frequency | Acceleration increment (g units) | Frequency | Velocity (mph) | Frequency |
| 177 to 180 | 1 | 0.6 to 0.7 | 1 | 102 to 108 | 1 |
| 180 to 183 | 0 | 0.7 to 0.8 | 0 | 108 to 114 | 1 |
| 183 to 186 | 2 | 0.8 to 0.9 | 0 | 114 to 120 | 2 |
| 186 to 189 | 1 | 0.9 to 1.0 | 2 | 120 to 126 | 3 |
| 189 to 192 | 1 | 1.0 to 1.1 | 2 | 126 to 132 | 3 |
| 192 to 195 | 0 | 1.1 to 1.2 | 1 | 132 to 138 | 3 |
| 195 to 198 | 2 | 1.2 to 1.3 | 2 | 138 to 144 | 3 |
| 198 to 201 | 5 | 1.3 to 1.4 | 3 | 144 to 150 | 6 |
| 201 to 204 | 5 | 1.4 to 1.5 | 2 | 150 to 156 | 7 |
| 204 to 207 | 1 | 1.5 to 1.6 | 5 | 156 to 162 | 10 |
| 207 to 210 | 0 | 1.6 to 1.7 | 6 | 162 to 168 | 3 |
| 210 to 213 | 1 | 1.7 to 1.8 | 10 | 168 to 174 | 3 |
| 213 to 216 | 4 | 1.8 to 1.9 | 9 | 174 to 180 | 6 |
| 216 to 219 | 0 | 1.9 to 2.0 | 1 | 180 to 186 | 3 |
| 219 to 222 | 3 | 2.0 to 2.1 | 4 | 186 to 192 | 3 |
| 222 to 225 | 4 | 2.1 to 2.2 | 3 | 192 to 198 | 2 |
| | | 2.2 to 2.3 | 5 | 198 to 204 | 1 |
| | | 2.3 to 2.4 | 1 | | |
| | | 2.4 to 2.5 | 2 | | |
| | | 2.5 to 2.6 | 1 | | |
| Total | 30 | Total | 60 | Total | 60 |
| $\bar{V}_{max}$ | 204.8 | $\overline{\Delta n}_{max}$ | 1.74 | $\bar{V}_o$ | 155.99 |
| $\sigma_V$ | 12.72 | $\sigma_{\Delta n}$ | 0.40 | $\sigma_o$ | 22.24 |
| $\alpha_V$ | -0.17 | $\alpha_{\Delta n}$ | -0.41 | $\alpha_o$ | -0.15 |

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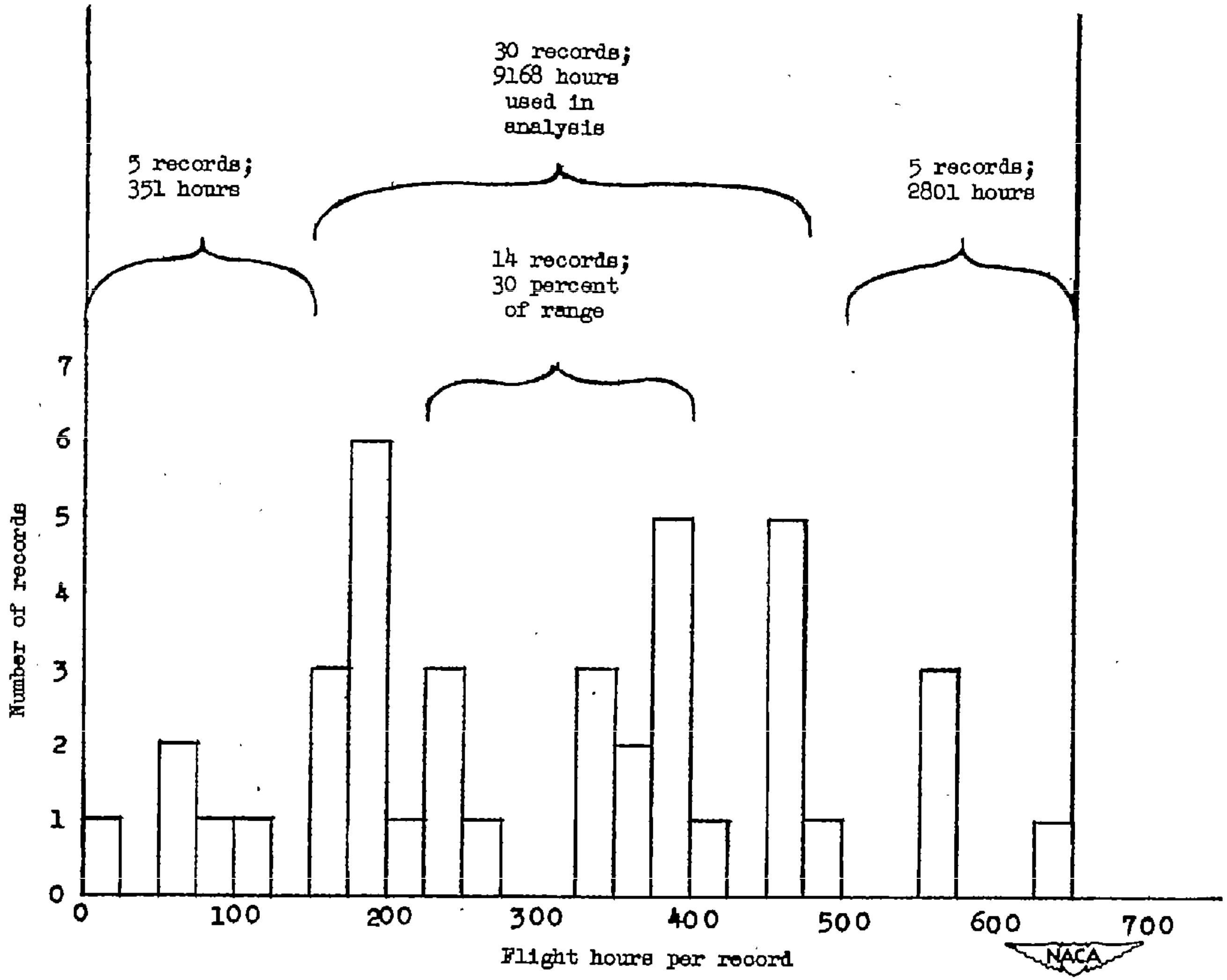


Figure 1.- Data supplied and data used in analysis.

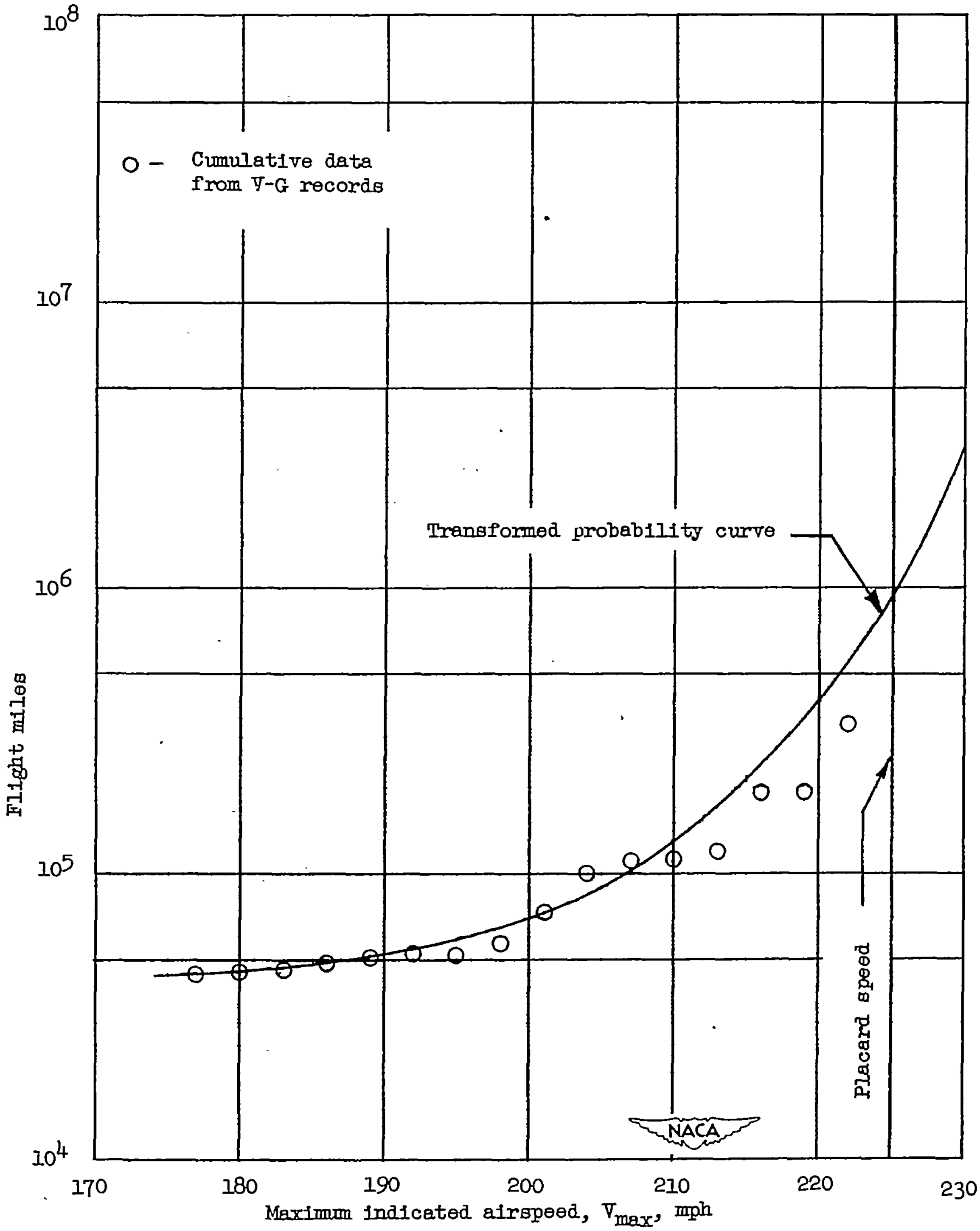


Figure 2.- Average number of flight miles required to exceed a given value of airspeed.

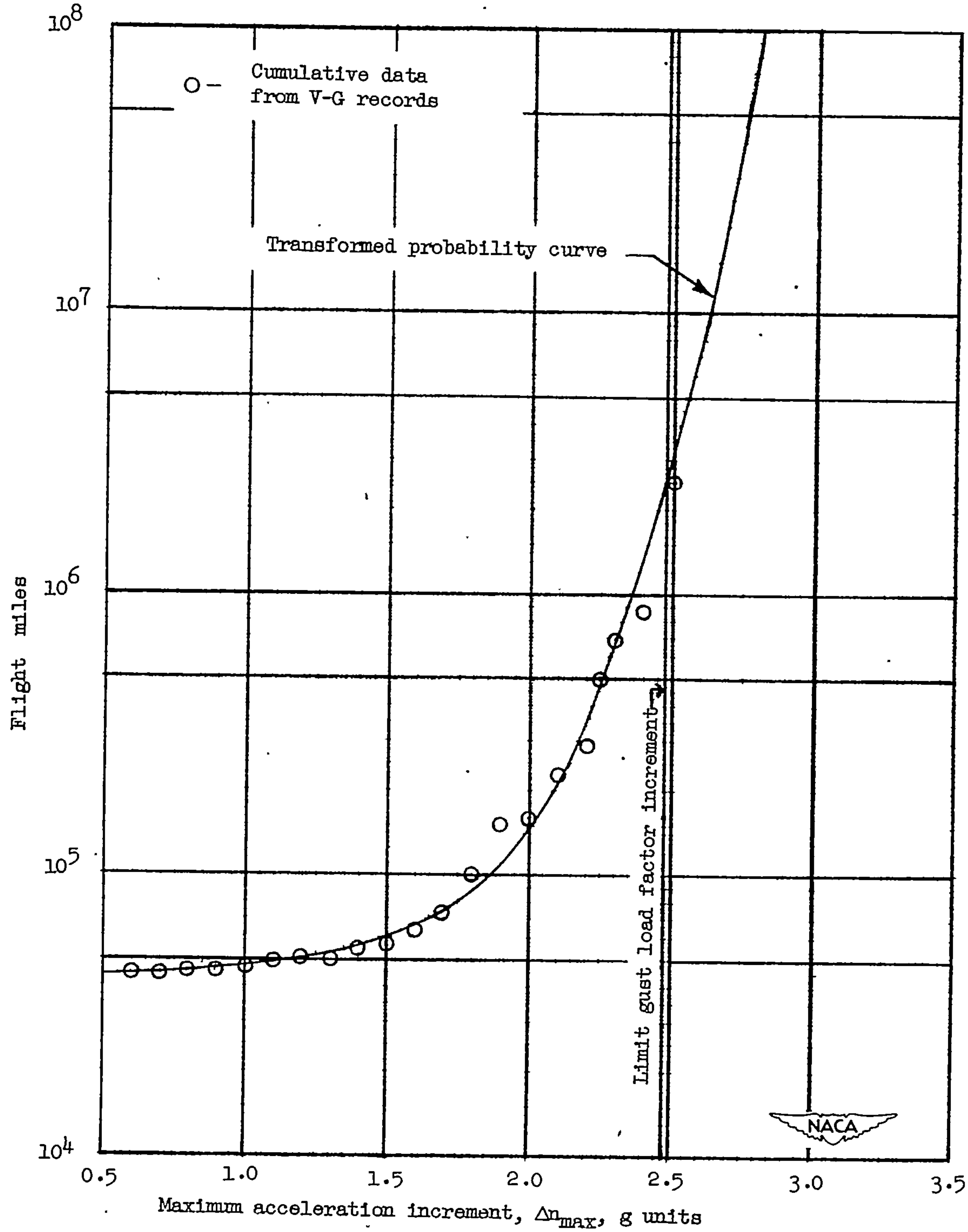


Figure 3.- Average number of flight miles required to exceed a given value of normal acceleration increment.

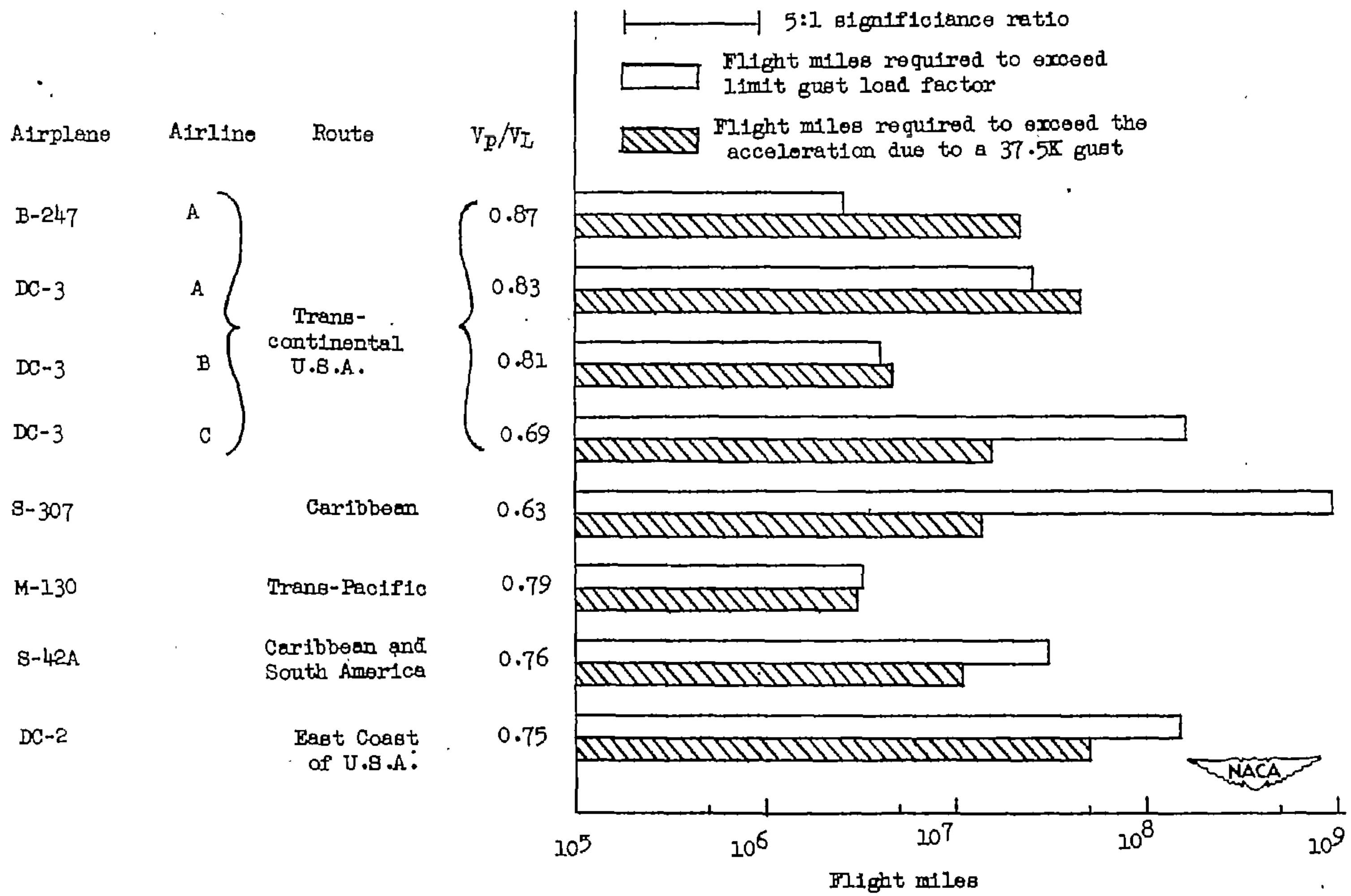


Figure 4.- Comparison of average flight miles required to exceed limit gust load factor and to exceed the acceleration due to an effective gust velocity of 37.5K feet per second at probable speed of maximum acceleration occurrence $V_p$.